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AIR–SEA INTERACTION AND REMOTE SENSING

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This final report concerns our research conducted under grant NAGW–1322 to the University of Washington from the Oceanic Processes Branch of the National Aeronautics and Space Administration. The proposed work consisted of two parts and our accomplishments in each one up to the present time is summarized below.

LONG RANGE OBJECTIVES

The long term objectives of this research are (*i*) to provide an improved parameterization of air–sea exchanges of momentum, heat and matter for use in long range forecasts and climatological modelling of the coupled atmosphere–ocean system and, (*ii*) to advance our understanding of remote sensing of the ocean surface.

I. EXPERIMENT ON R/P FLIP

I.1 Scientific Objectives: The first part of the proposed research was a joint effort between our group and Drs. Andrew Jessup and Peter Dahl of the Applied Physics Laboratory (APL), University of Washington. Our own research goal was to investigate the relation between the air–sea exchange processes and the sea state over the open ocean and to compare these findings with our results obtained over a small body of water namely, Lake Washington. The goals of the APL researchers were to study (*i*) the infrared sea surface temperature (SST) signature of breaking waves and surface slicks (by A. Jessup under a NASA grant) and , (*ii*) microwave and acoustic scattering from water surface (by P. Dahl and A. Jessup with support from an ONR–ARL program). The task of our group in this joint effort was to conduct measurements of surface fluxes (of momentum, sensible heat and water vapor) and atmospheric radiation (solar and terrestrial) to achieve our research goal as well as to provide crucial complementary data for the APL studies.

I.2 Accomplishments: The field experiment took place off the California coast between January 12 and February 2, 1992. A summary of the data sets acquired were submitted to NASA in our progress report for FY–92. The results obtained from the analyses and interpretation of the acquired data are summarized below.

The reason for selecting this particular time and location for the experiment was that during winter this area is frequently subject to high winds. However, during almost the entire period of the experiment the site was under the influence of unusually low winds, generally less than 5 *m/s*. At such low wind speeds the K–Gill anemometer is not suitable for measurements of the turbulent wind components (Ataktürk and Katsaros, 1989). In addition, when measurements are conducted from a platform that is subject to motions due to the wave action, as on R/P FLIP, the data must be corrected for the platform motions before the fluxes can be determined by the eddy correlation method. Under such conditions, the minimum wind speed for determination of surface fluxes by using a K–Gill anemometer is about 7 *m/s* (Anctil *et al*, 1994). Therefore, surface fluxes could not be determined with adequate accuracy from the FLIP data set using the only direct method of eddy correlation.

Another consequence of the unusually low winds was either a glossy water surface or very small wind generated waves. On the other hand, large swell generated by the distant storms constantly propagated into the region. The wave energy spectra obtained from measurements of wave heights were dominated by the swell such that the peak associated with the wind waves could not be distinguished.

For the reasons mentioned above the FLIP data sets were not suitable to pursue our own research goals concerning the relationships between the directly–measured surface fluxes and wind waves over the open oceans.

However, the same experimental conditions allowed detailed investigation of the water skin temperature by the APL group (of Dr. A. Jessup). Our contribution to this effort was determination of the net heat flux across the ocean–atmosphere interface. To this end, we provided (*i*) the radiative heat flux based on our measurements of the solar and infrared radiation and, (*ii*) the turbulent fluxes of sensible and latent heat estimated from a bulk aerodynamic parameterization particularly designed for low winds (Liu, Katsaros and Businger, 1979). The results are presented in the following publications.

I.3 Publications:

Zappa, C.J., 1994: Infrared field measurements of sea surface temperature: analysis of wake signatures and comparison of skin layer models. M.S. thesis, Univ. of Wash., 205 pp. (Also, *Technical Report*, **APL–UW TR 9412**, August 1994.)

Jessup, A.T. and V. Hesany, 1995: Modulation of ocean skin temperature by swell waves. *J. Geophys. Res.* (submitted) *(Copies are included with this report.)*

II. EXPERIMENT ON LAKE WASHINGTON

II.1 Scientific Objectives: This part of our research is focused on the detailed study of the relationships between wind waves, surface roughness and fluxes of momentum, sensible heat and water vapor.

II.2 Accomplishments: Field experiments conducted at our tower on Lake Washington included measurements of surface fluxes (of momentum, sensible heat and water vapor), wave heights using a single wire and an array of 8 wire wave staffs, and microwave backscatter from the rough water surface.

Surface Fluxes: We have been conducting measurements of surface fluxes at this site over several years. The results based on these measurements have been reported to NASA previously (Ataktürk, 1991). Further analyses of these data sets showed that the magnitudes of surface fluxes are generally in agreement with the results obtained from other similar field studies. However, we also found that under the conditions of stable atmospheric stratification, the similarity between the turbulent transfers of sensible heat and water vapor breaks down such that the efficiency of atmospheric turbulence in transporting the latent heat is reduced approximately by 50%. A manuscript (Ataktürk and Katsaros, 1996a) on these findings is under revision.

Amplitudes of Surface Waves: Ataktürk (1991) noted that the growth of wave amplitudes on Lake Washington is smaller than that on larger bodies of water while the dominant frequencies are in excellent agreement. These findings are important for applications in coastal zones and estuaries and, are further discussed in the manuscript by Ataktürk and Katsaros (1996a).

Wave Breaking: Detailed studies of the breaking of pure wind waves were carried out on Lake Washington. The statistics based on our observations showed that the incidence of wave breaking depends on both the level of wave development as determined by inverse wave age and the wind forcing. These results are described by Katsaros and Ataktürk (1992).

Directional Spreading of Wind Waves: Complete description of a wave field requires knowledge on the distribution of the wave energy with respect to all frequencies (wavenumbers) over all possible directions. Our previous single–point measurements on Lake Washington have provided information on the frequency distribution, but not on the angular spreading of the wave energy. During FY93, we completed testing the hardware of our new 8–wire wave array, its calibration in the field and developing the software for data analysis. Results from a performance test of the wave array and a sample directional wave spectrum obtained using the field data were provided to NASA previously (*Appendix A*, Report FY94). Analysis of the complete data set is in progress. The results in hand show that directional spreading of surface waves is narrow and unimodal near the spectral peak and broadens with increasing frequency. This is consistent with the previous measurements (Mitsuyasu *et al*, 1975, Hasselmann *et al*, 1980, Donelan *et al*, 1985). Recently, Young *et al* (1995) reported that at frequencies about twice the peak frequency, the unimodal spreading becomes bimodal. Our results indicate that this behavior is observed at large inverse wave age only and otherwise the spreading is still unimodal. These findings (Ataktürk and Katsaros, 1996b) will be presented in a meeting or published as a short note.

Microwave Backscatter: This part of the research was carried out jointly with the University of Kansas at our site. Dr. P. Gogineni and his group conducted the measurements of the microwave radar backscatter from the rough water surface. Our contribution was the detailed descriptions of the wave field (from a single–wire wave gauge) and the environmental conditions including wind speed, friction velocity and atmospheric stratification. Using these data sets we have shown that small scale waves are advected by the surface currents evaluated not at the free interface but at a depth proportional to their wavelengths. Support for this result on the differential advection of small scale waves was provided through comparisons of the modulation of the short waves by the underlying long waves as determined from measurements of radar backscatter and wave heights. These findings described by Ataktürk and Katsaros (1994) were presented in a symposium, *The Air–Sea Interface*, Marseilles, France, June 24–30, 1993.

II.3 Publications:

Ataktürk, S.S., 1991: Characterization of roughness elements on a water surface. Ph.D. Dissertation, Department of Atmospheric Sciences, University of Washington, Seattle, WA, 98195, 196 pp. *(Copies were provided to NASA previously.)*

Ataktürk, S.S. and K.B. Katsaros, 1994: Water surface currents, short gravity–capillary waves and radar backscatter. In *The Air–Sea Interface*, M.A. Donelan, W.H. Hui and W.J. Plant, Eds., The University of Toronto Press, Toronto. *(Copies are included with this report.)*

Ataktürk, S.S. and K.B. Katsaros, 1996a: Wind waves and surface fluxes of momentum, heat and water vapor observed on Lake Washington. *J. Phys. Oceanogr.* (in revision). *(Copies were provided to NASA previously.)*

Ataktürk, S.S. and K.B. Katsaros, 1996b: Directional Spreading of Wind Waves Near and Above the Spectral Peak: Dependence on Wind Forcing (in preparation).

Katsaros, K.B., and S.S. Ataktürk, 1992: Dependence of wave breaking statistics on wind stress and wave development. Presented in *International Union of Theoretical and Applied Mechanics, IUTAM, Breaking Wave Symposium*, Sydney, Australia, 15–19 July, 1991. (To appear in symposium volume edited by Roger Grimshaw and M.L. Banner.) *(Copies were provided to NASA previously.)*

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Mitsuyasu, H., F. Tasai, T. Suhara, S. Mizuno, M. Ohkuso, T. Honda and K. Rikiishi, 1975: Observations of the directional spectrum of ocean waves using a cloverleaf bupoy. *J. Phys. Oceanogr.*, **5**, 750–760.

Young, I.R., L.A. Verhagen and M.L. Banner, 1995: A note on the bimodal directional spreading of fetch–limited wind waves. *J. Geophys. Res.*, **100**, No. **C1**, 773–778.